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A STUDY ON SEISMIC VULNERABILITY ASSESMENT OF AN UNSYMETRICAL RC RESIDENTIAL BUILDING IN INDIA

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ABSTRACT

Experience in past earthquakes has demonstrated that Earthquakes are one of the nature's greatest hazards on our planet which have taken heavy toll on human life and property since ancient times. The sudden and unexpected nature of the earthquake event makes it even worse on psychological level and shakes the moral of the people. Man looks upon the mother earth for safety and stability under his feet and when it itself trembles, the shock he receives is indeed unnerving. These recent devastating earthquakes have exposed the vulnerability of the existing reinforced concrete buildings in India. The recent earthquakes of 2001 & 2005 saw a great deal of damage to RC buildings in Gujarat & J&K. This has posed a serious threat to the many existing RC buildings in India which are designed mainly for gravity loads. Keeping in view the devastation caused by the past earthquakes especially in developing countries like India, the importance of safe & stable structures has increased many folds. This leads to need for proper evaluation of the seismic adequacy in the existing structures.

In order to assess the vulnerability, a simplified procedure for evaluation is highly in need for a country like India which is prone to earthquakes. It is important to estimate the response of buildings under earthquakes from the viewpoint of life reservation and risk management. The adequacy and the performance of the building are checked with the codal provisions of IS 1893:2002. In addition to this a visual evaluation of the building from the view point of damage that it could suffer during an earthquake. A procedure for evaluating the seismic performance of existing building in India is proposed. The procedure is based on the capacity spectrum method (ATC 40) and is intended to provide practicing engineers with a methodology for determining the performance level of the building. The distribution of lateral forces used in pushover analysis is as given in IS1893 (Part 1): 2002. The proposed methodology is applied to a representative Reinforced Concrete Moment Resisting Frame (RC) building. This procedure gives an in-depth sight into the distribution of damage and the global failure mechanism. This will help in deciding the retrofitting requirements for the building if needed.

KEYWORDS: Catastrophic Damage, Non-Engineered Buildings, Seismic Inadequacy, Lack of Proper Seismic Knowledge, Details of Seismic Resistant Construction, Proper Seismic Evaluation

INTRODUCTION

The seismic vulnerability of a structure is its weakness in the face of anticipated earthquakes. A structure with higher vulnerability is likely to suffer severe damage. The need for evaluating the seismic adequacy of

existing buildings has come into focus following the enormous loss of life and property during the recent earthquakes in India. After the Bhuj Earthquake (2001) & Kashmir Earthquake in (2005) considerable interest in this country has been directed towards the damaging effect of earthquakes and has increased the awareness of the threat of seismic events .USGS estimates that around 5 lakh earthquakes hit the Earth every year, 1 lakh of those can be felt, and very few cause damage [http://earthquake.usgs.gov/learn/facts.php]. Moreover, in Indian-Subcontinent, particularly the north-eastern and north-western regions are the most earthquake prone regions of the world. 1988 Bihar earthquake, 1991 Uttarkashi earthquake, 1993 Killari earthquake, 1997 Jabalpur earthquake, 1999 Chamoli earthquake, 2001 Bhuj earthquake, 2002 Andaman earthquake, 2004 Sumatra earthquake, 2005 Kashmir earthquake, 2011 Sikkim earthquake are some of the worst hit earthquakes, which cumulatively have caused over 1 lakh death toll. Seismic zonation clearly shows that India is highly vulnerable to earthquake hazard. During last 100 years, India has witnessed more than 650 earthquakes of magnitude _ 5.0 [Kamalesh Kumar, 2008]. In addition to very active northern and north-eastern range, the recent events of 1993 Killari (Maharashtra) and Jabalpur (Madhya Pradesh) in the Peninsular India have started raising doubts as the disasters caused by these earthquakes are alarmingly increasing. Earthquake events reporting from the Himalayan mountain range, Andaman and Nicobar Islands, Indo-Gangetic plain as well as from peninsular region of India belongs to subduction category and a few events had also been under intra-plate category.

A large number of existing buildings in India need seismic evaluation due to various reasons such as, non compliance with the codal requirements, updating of codes and design practice and change in the use of building. The evaluation of the seismic performance of buildings that are designed for gravity loads is governed by the modeling of certain detailing aspects such as discontinuous positive flexural reinforcement, lack of joint shear reinforcement; and inadequate transverse reinforcement for core confinement which are inherent in the existing buildings in India. Most reinforced concrete (RC) buildings in India are framed constructions with unreinforced masonry infill ranging from 2 to 8 storey. Mid rise buildings (4 to 8 storey) having open ground storey for parking facilities is a common construction practice in the whole of India. These buildings have undergone major damage in the recent earthquakes. Soft storey mechanism of failure is observed in many of the cases. The analytical technique proposed in ATC40 [1] uses the capacity spectrum approach. The capacity spectrum method requires the construction of the strength capacity curve expressed in standard acceleration versus period format and compared with the elastic response displacement response spectra earthquake demands. The strength capacity curve is established from a pushover analysis by the code based parabolic loading distribution (loading proportional to the first mode shape). The structural capacity and the demand are represented in the acceleration displacement response spectrum format introduced by Mahaney et al. [2]. This procedure provides an estimate of the performance in terms of storey drift and possible failure mechanism. This paper brings out the intricacies in modeling such inadequacies through pushover analysis.

RESEARCH SIGNIFICANCE

In a seismically active region like India, there is potential risk for existing RC buildings. The need for a simple yet reliable evaluation of existing buildings is of growing concern to the practicing community. While analytical tools for nonlinear static analysis exist, the real issue is whether the modeling of certain non ductile detailing is properly accounted for in the evaluations. The purpose of this study is to provide a simple rational procedure to analyze existing RC buildings that were designed for gravity loads. The procedure allows modeling of non ductile detailing in an implicit manner so that existing analytical tools can be used to carry out the required seismic evaluation. The analysis provides an insight into the

behaviour of the components and the failure mechanism of the structure as a whole. The evaluation procedure is applied to typical four storey RC building that reveals the inherent deficiencies as compared to current earthquake resistant design requirements in India.

BACKGROUND AND PREVIOUS RESEARCH

Though the evaluation of vulnerability of existing RC MRF buildings is not new the application of the same techniques to non ductile or gravity load designed buildings is not so well developed in India. Various computational tools are available in the published literature comprising of analytical models and procedures. They systematically predict the vulnerability associated with the buildings and give an assessment of the risk level either qualitatively or quantitatively. To this end, in the recent past, ATC-40 has covered the standard recommendations and the guidelines for the seismic assessment. However, these procedures will have to be checked for their applicability in the case of Indian buildings. This paper follows the ATC-40 procedure to perform the push-over analysis to assess the vulnerability of existing RC buildings.

DESCRIPTION OF ZONE-III BASED COMMON RESIDENTIAL RC BUILDING

The building configuration selected was a representative residential building that is common in seismic zone-III. An asymmetric floor plan with 1.5m footing depth and floor levels of equal height (3.15m) were used to analyze through pushover analysis. Which was performed by SAP 2000 to check the possible failure mechanism through the creation of pushover curve and to see the deficiencies present even after designing it by provision of IS 1893. The residential building (Figure 2) which is taken for study purpose content irregular distribution of mass at each floor and it also have other nonstructural element like cantilever portion of projected length of 1.23m. Figure 1 and Figure 3 shows the elevation and floor plan of a typical 2storey residential building.

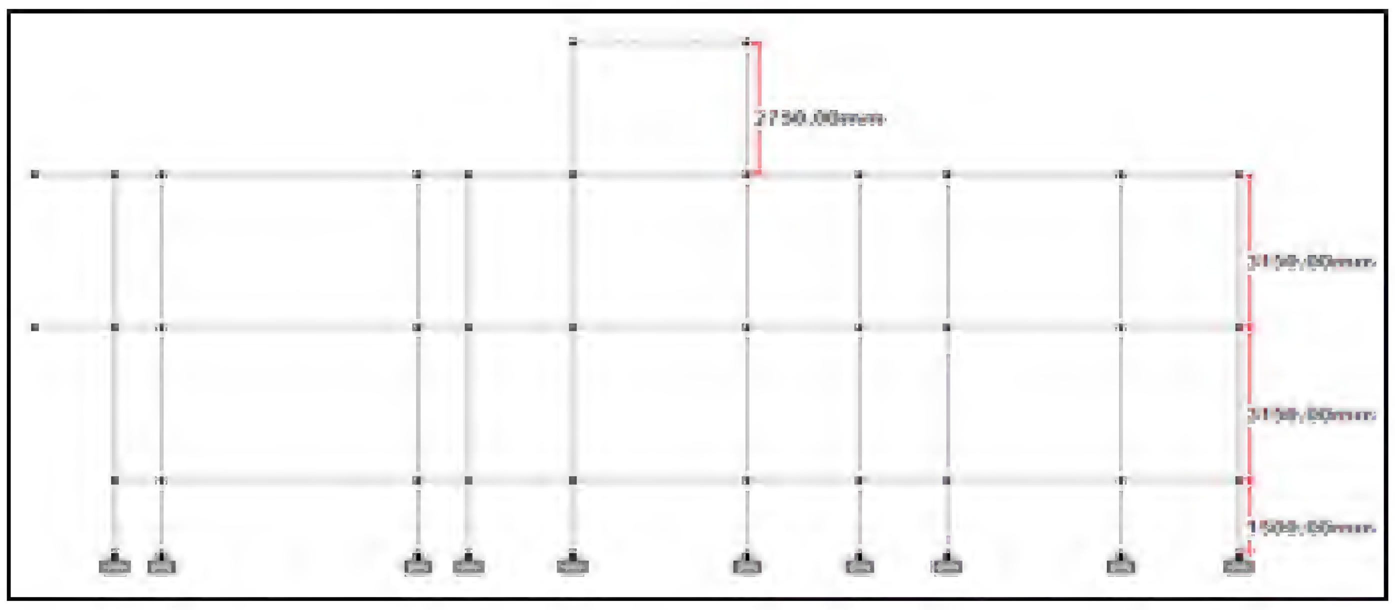

Figure 1: Elevation of Building

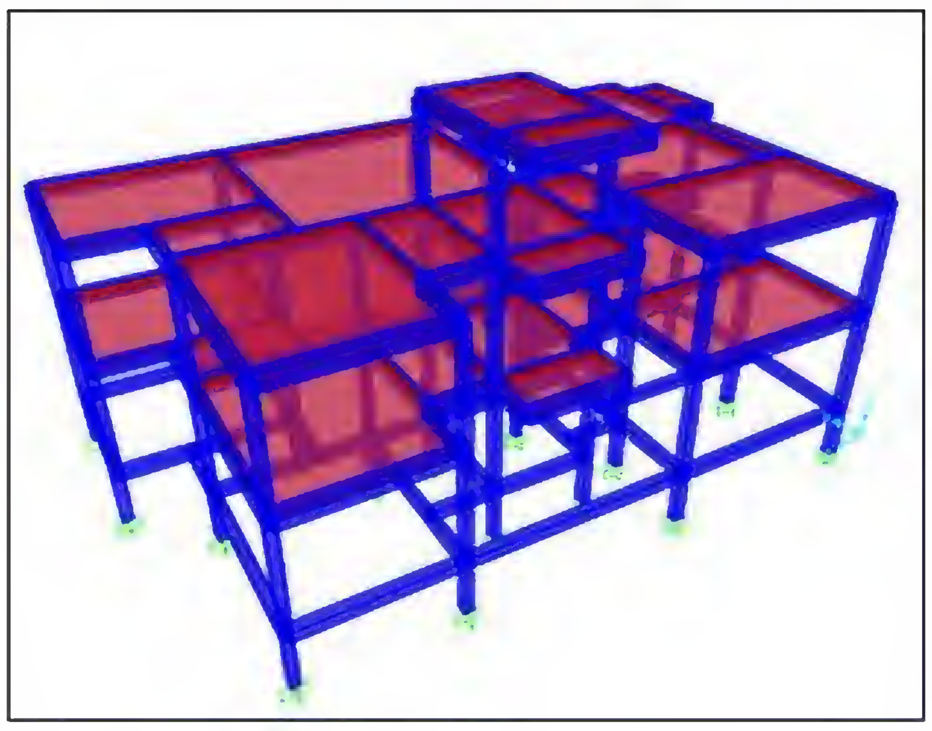

Figure 2: 3D Rendered View

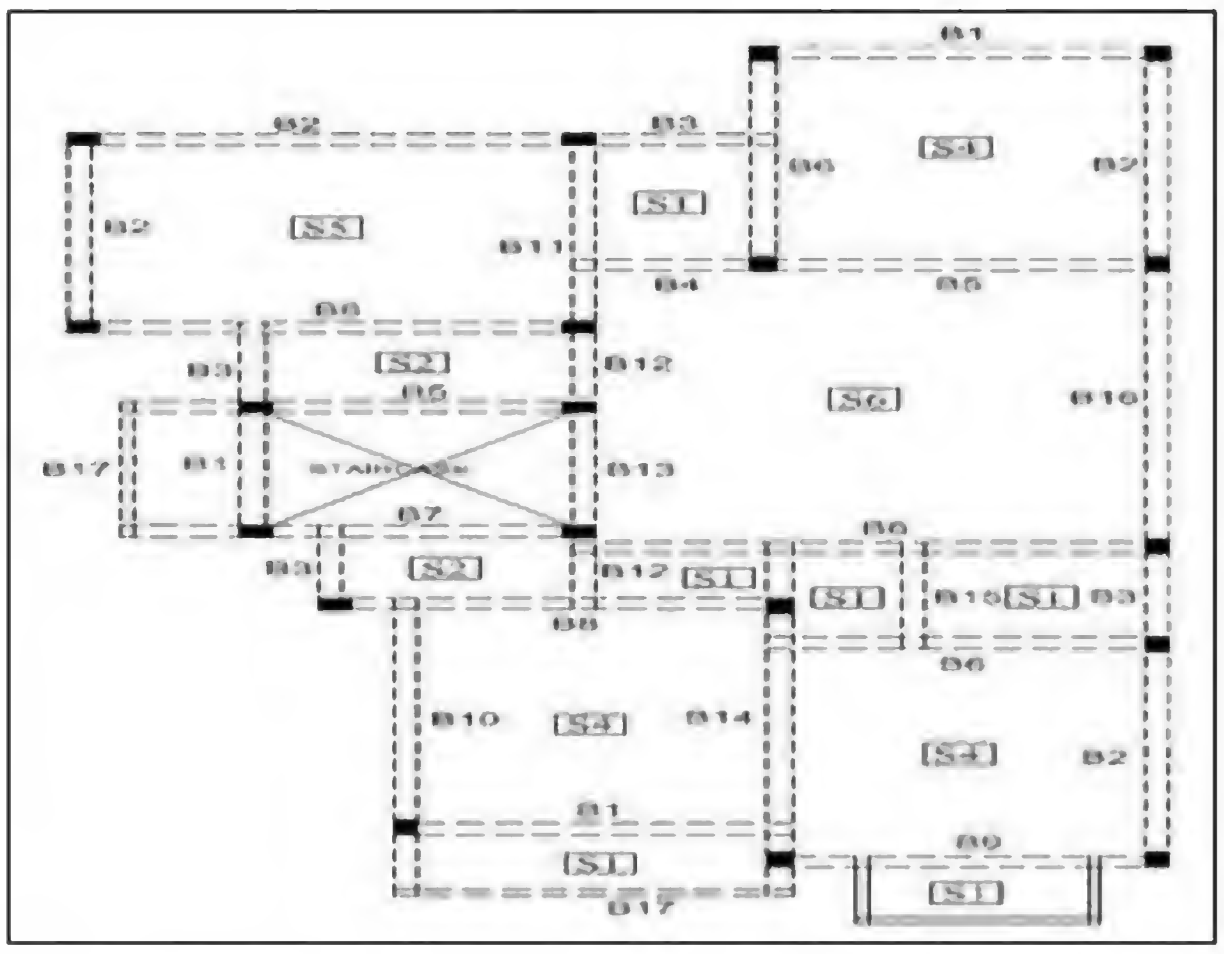

Figure 3: Building Plan

GENERAL ASPECTS OF INDIAN RC MRF BUILDING

The buildings were designed for lateral loads and considered in accordance with code requirements prescribed in IS456:2000 [3]. The grade of concrete considered is M20 and that of reinforcement steel is Fe415. Dead loads are computed considering the unit weight of concrete as 25 kN/m3 having slab thickness of 150mm and the live load on the ground floors, first floors and for slab at the staircase well are taken as 2.0kN/m2,1.5 kN/m2 and 0.75kN/m2 respectively from IS 875 (Part 2): 1987 [5]. The reinforcement patterns were arrived on the basis of lateral load design as per IS 456-2000 and the details are given in Table 1 and in Figure 4.

Table 1: Beam Reinforcement Detail

SR. NO.	TIE BEAM NO.	BEAM SIZE		LONGITUDINAL REINFORCEMENT				STIRRUPS	
				TOP FACE REINFORCEMENT		BOTTOM FACE REINFORCEMENT		END ZONE '2L'STPS	MIDDLE ZONE '2L'STPS
		W mm	D mm	Ast1 (Thro.at Top.)	Ast2 (Extra at support)	Asb1 (Thro.at Bottom.)	Asb2 (Extra at middle)		
1	B1	230	450	2#16	2#12	2#16	1#12	#8@100	#8@175
2	B2	230	450	2#16	2#16	2#16	1#12	#8@100	#8@175
3	B3	230	450	2#16	-	2#16	-	#8@200	#8@200
4	B4	230	450	2#16	-	2#16	-	#8@200	#8@200
5	B5	230	450	2#16	2#16	2#16	1#16	#8@200	#8@175
6	B6	230	450	2#16	2#16	3#16	-	#8@100	#8@175
7	B7	230	450	2#16	1#16	3#16	-	#8@125	#8@200
8	B8	230	450	2#16	3#16	3#16	2#16	#8@100	#8@175
9	B9	230	450	2#16	2#16	3#16	2#12	#8@100	#8@175
10	B10	230	450	2#16	2#16	2#16	2#12	#8@100	#8@175
11	B11	230	450	2#16	2#16	3#16	-	#8@100	#8@175
12	B12	230	450	2#16	-	3#16	-	#8@100	#8@175
13	B13	230	450	2#16	1#16	3#16	-	#8@100	#8@150
14	B14	230	450	2#16	2#16	3#16	2#16	#8@100	#8@175
15	B15	230	450	2#12	-	3#12	-	#8@100	#8@175
16	B16	230	450	2#16	3#16	2#16	2#16	#8@100	#8@175

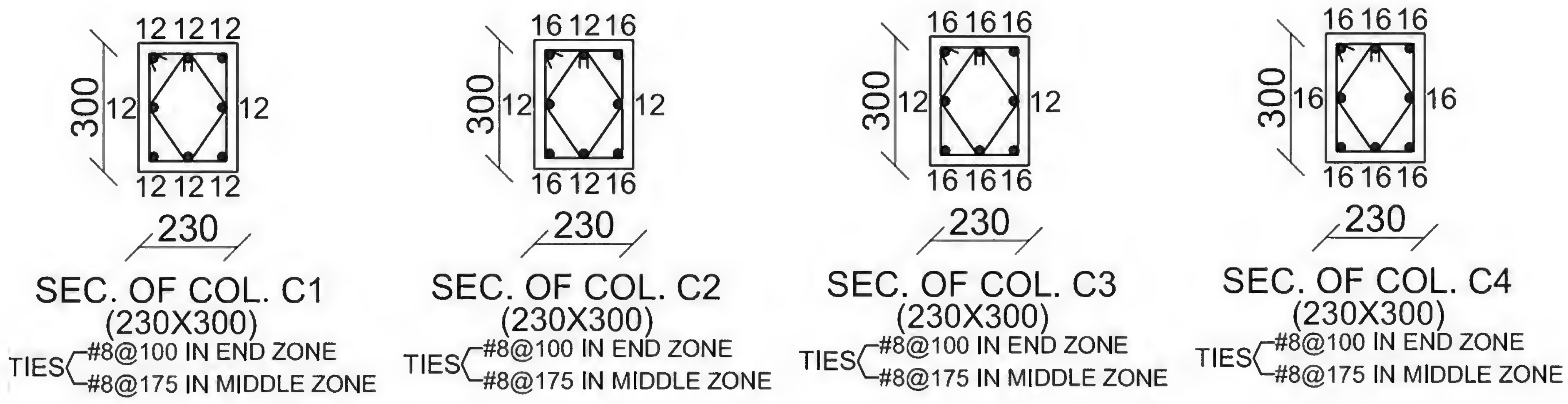

Figure 4: Column Reinforcement Detail

DEFICIENCIES OF RCC BUILDINGS IN INDIA

Deficiencies mainly occur due to improper detailing. If detailing is not done properly which is required by the provision of IS 13920: 1993 leads to catastrophic damage in buildings main structural or load bearing component through the creation of possible plastic hinges. This leads to creation of mechanism called as rigid body motion in building, susceptible to collapse. These contribute to the vulnerability of the RC building under seismic loads. The first issue is the transverse reinforcement required for ductile detailing in column and beam plastic hinge zones. In this building the amount of transverse reinforcements provided in beams in the plastic hinge zone is 8 @ 100mm c/c in end zone and 8 @ 175mm c/c in middle zone ,whereas in column ties required in that region is 8 @ 100mm c/c as per IS13920:1993 [6].

MODELING ASPECTS

Computational Tool: SAP2000 NL

The computer program SAP2000NL [7] is used for pushover analysis. The nonlinear static procedure of ATC 40 is implemented in SAP2000 NL which feature is in the present analysis. The unique capability of the program is the definition of plastic hinge properties and the nonlinear static analysis tool. It allows for the direct input of moment rotation properties characteristic of sections. SAP2000 NL uses the moment rotation backbone curve from ATC40.

Modeling of Structural Elements

The primary structural elements of the RC MRF such as beams and columns are modeled as three dimensional frame elements with point plasticity at the end faces of beam and column. The contribution of infill stiffness is disregarded in this particular study but their weight is included in mass computations. The effective moment of inertia of 0.7 I_g (I_g is the gross moment of inertia) is considered for modeling the beams and columns. The foundation is treated to be fixed and the building is assumed to be in Zone III as per IS1893 (Part 1):2002 [8].

Modeling of Confinement

The moment rotation properties for beams and columns are obtained from Table 9.6 and 9.7 of ATC-40 depending on the level of transverse reinforcement provided in the sections. Generally flexural hinge (M3) is assigned for beams and axial moment hinge (PMM) for columns. The PMM hinge properties include moment theta relations as well as the interaction curve given as per ACI 318 [9]. The building was verified for the possibility of shear failures in the flexural components and it was found to be safe against such failures.

EVALUATION METHODOLOGY

Nonlinear Static Analysis Procedure (Pushover Analysis)

The analysis is performed using the tool SAP2000 NL. The pushover analysis follows the nonlinear static procedure. It essentially adopts the capacity spectrum method proposed by ATC-40. This method of evaluation considers two aspects, the performance of a structure during seismic event, and the strength/capacity of the structure. The structure has been idealized as a 3D finite element model constructed with elastic frame elements having point plasticity at the possible plastic hinge locations. A lateral force distribution in accordance with IS 1893:2002 is applied to the analytical model. The force deformation relationship is defined as per the ATC-40 guidelines which follows the convention below:

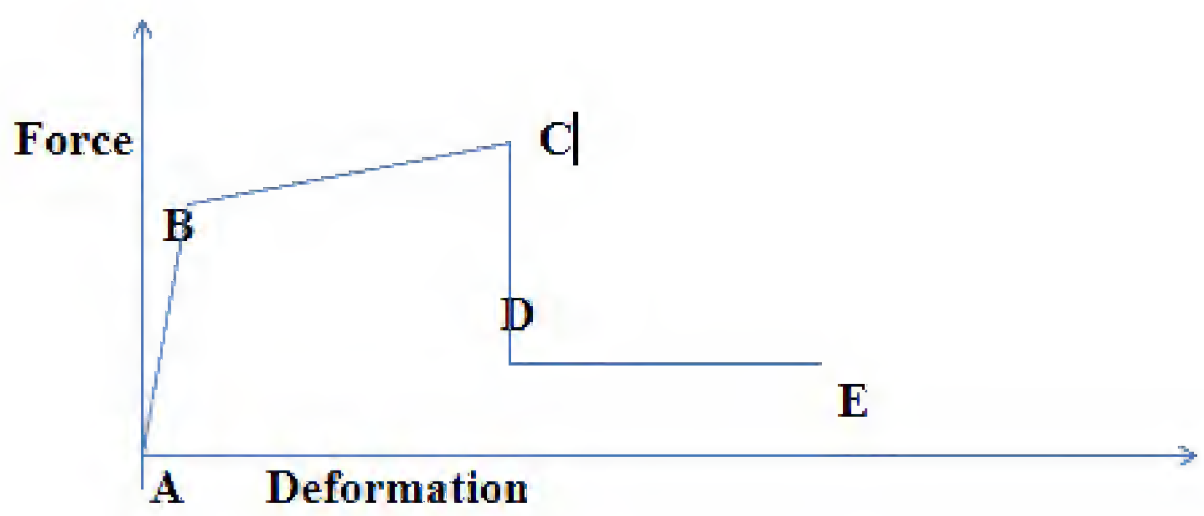

Figure 5: Prescribed ATC-40 Force Deformation Relationship

Three different pushover cases have been performed in sequence as follows:

- Gravity push, which is to apply gravity load (DL+0.25 LL)
- Lateral push in the X-direction
- Lateral push in the Y-direction

In general, the gravity load push is force controlled while the lateral push is deformation control. The displacements are monitored at the roof level. This includes the effect of secondary moments due to large deflections (P-Δ effect). The responses of the structure are the capacity curve representing the base shear versus roof displacement, the sequence of hinge formation and the capacity spectrum curve in ADRS format. Building performance can be described by the extent of damage sustained by the building, which influences the safety of the building occupants during and after the event. In this study, the performance objectives have been imposed to satisfy the code compliance and to insists favorable failure pattern preferably a strong column-weak beam mechanism.

RESULTS AND DISCUSSIONS

The building time period is estimated as 0.4843s from the Eigen value analysis with the code estimated period being 0.25s. The building base shear capacity from pushover analysis is 610 kN and a maximum displacement of 0.1006m. The plot of the base shear versus the displacement for PUSHX and PUSHY case is shown in Figure 8 & Figure 9 respectively. The capacity curve and the demand curve for the building is represented in the ADRS format and the intersection of the curves resulting in the performance point is shown in Figure 6 and Figure 7. The possible failure mechanism of the building and in specific column hinging at the ground level and beam hinging in the floor levels is clearly depicted in Figure 10 Figure 11 for PUSHY and PUSHX respectively. Column hinging in between the storey is another feature representative in this building. The performance point for PUSHX case is obtained at a base shear level of 580.274 kN and a displacement of 0.072 m and for PUSHY the base shear is 634.849 and roof displacement is 0.071m

which lies below the performance objective required for Life safety of 2% of building height (0.181m). The building fails to satisfy the required performance objective of life safety under a maximum credible earthquake.

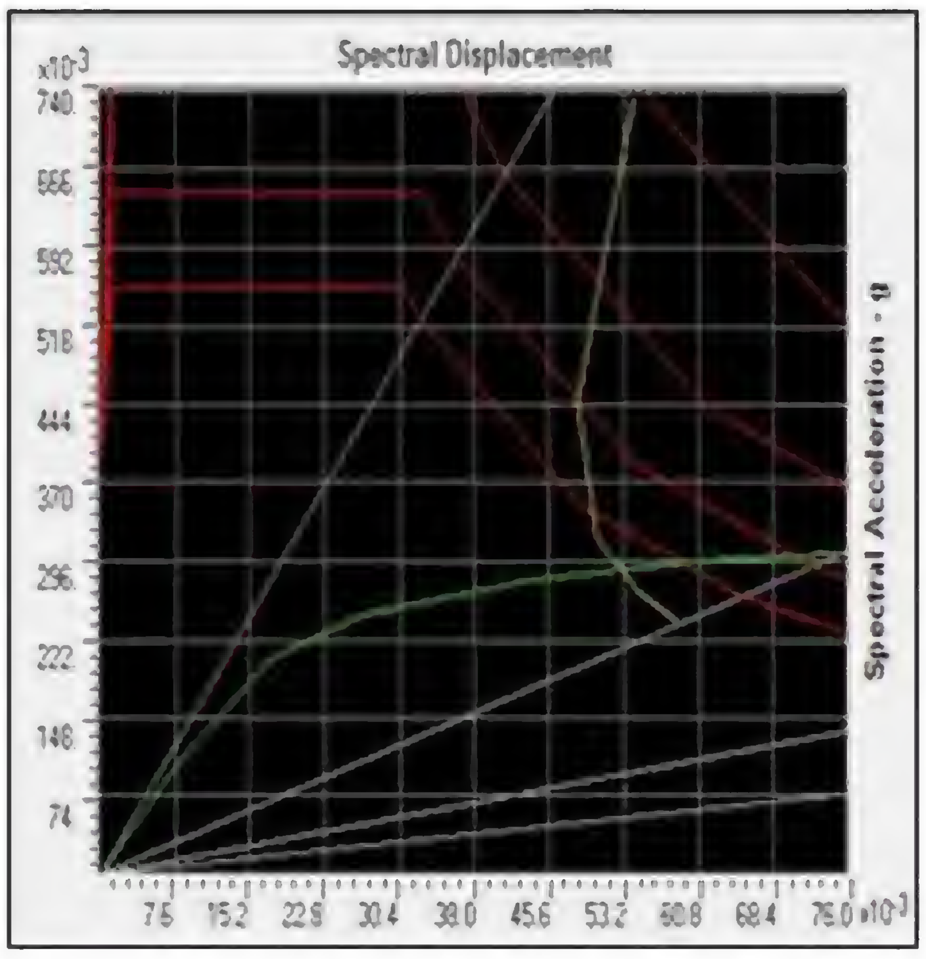

Figure 6: Capacity and Demand Curve in ADRS Plot Due to PUSHX Case

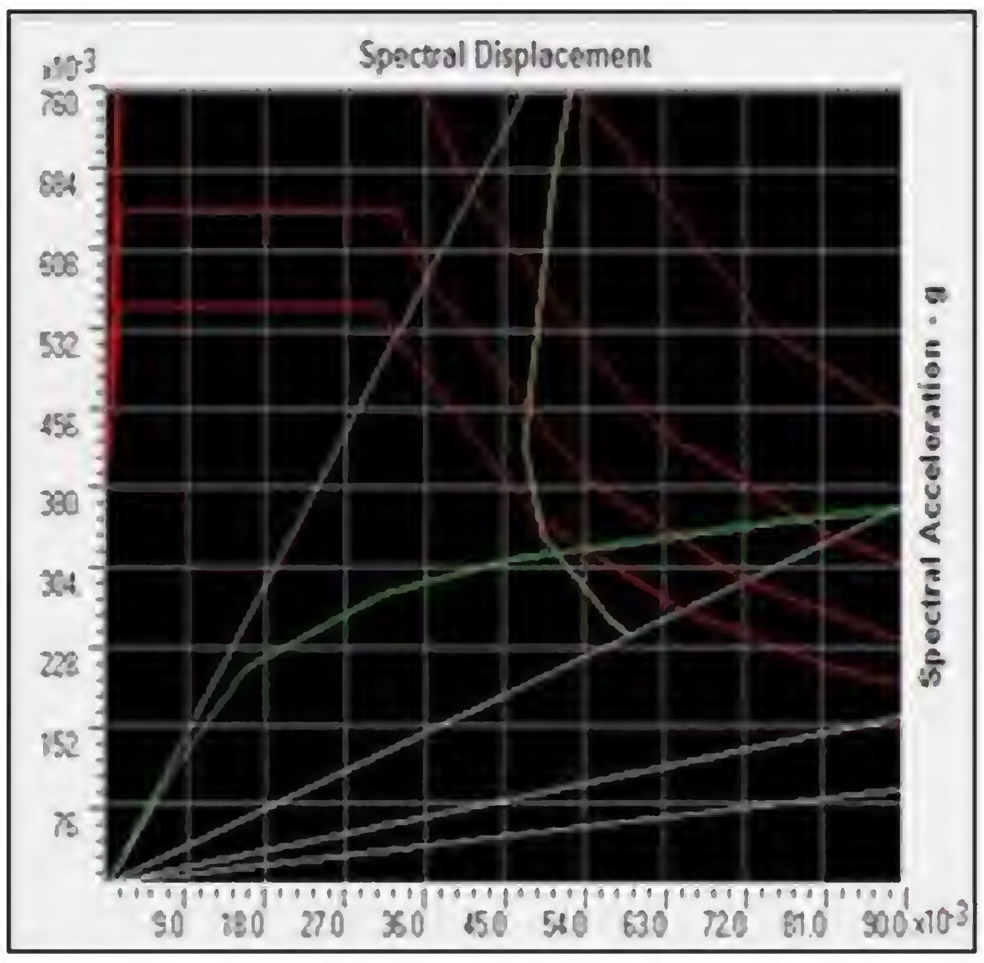

Figure 7: Capacity and Demand Curve in ADRS Plot Due to PUSHY Case

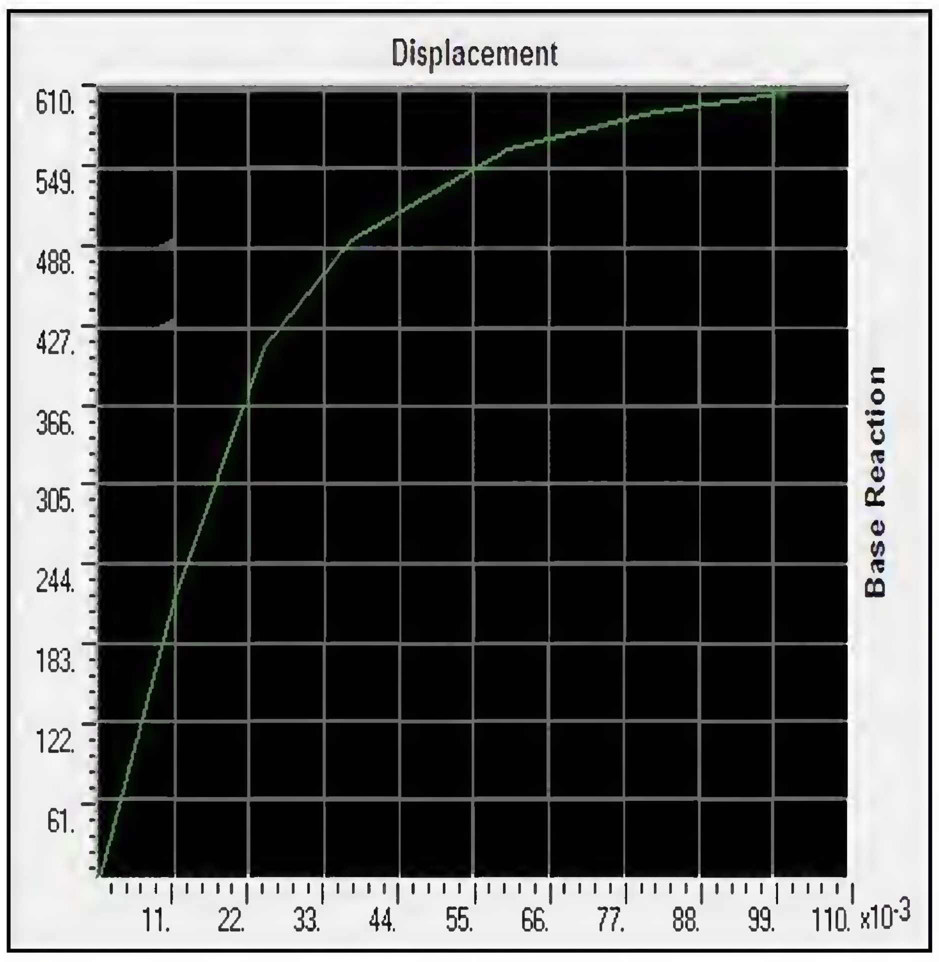

Figure 8: Capacity Curve for Two Storey Building Due to PUSHX Case

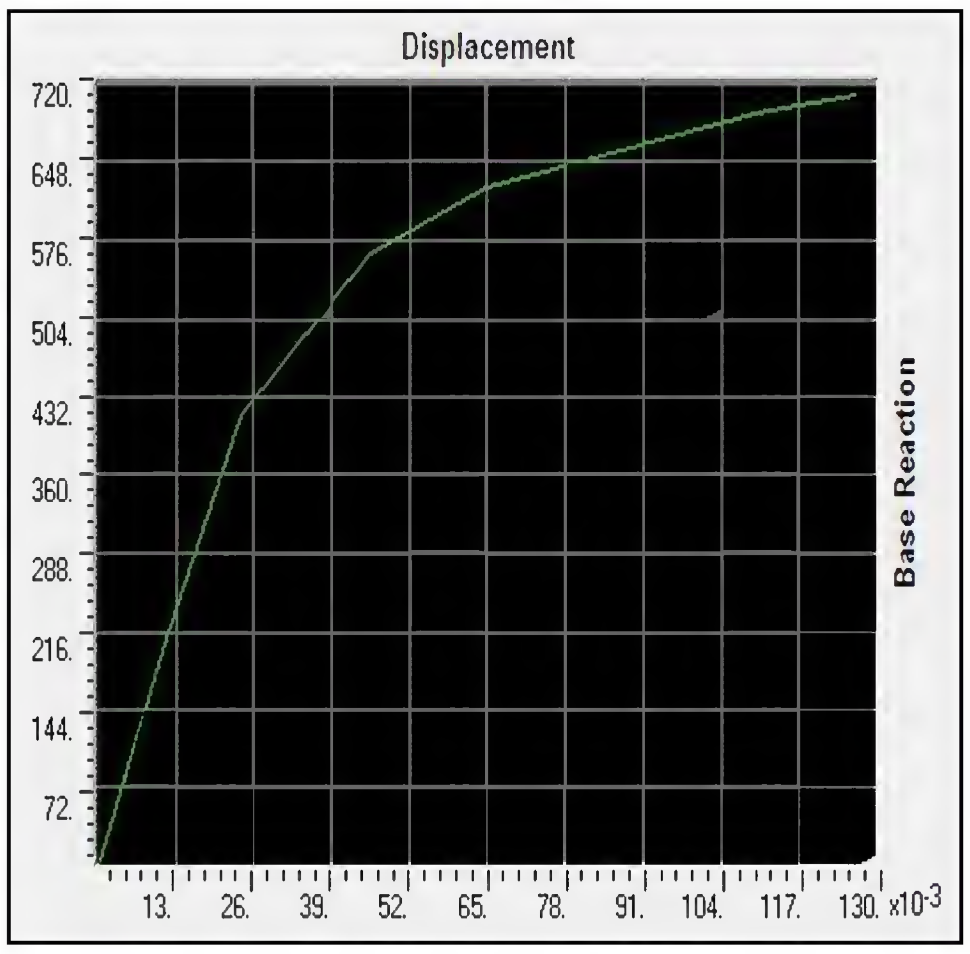

Figure 9: Capacity Curve for Two Storey Building Due to PUSHY Case

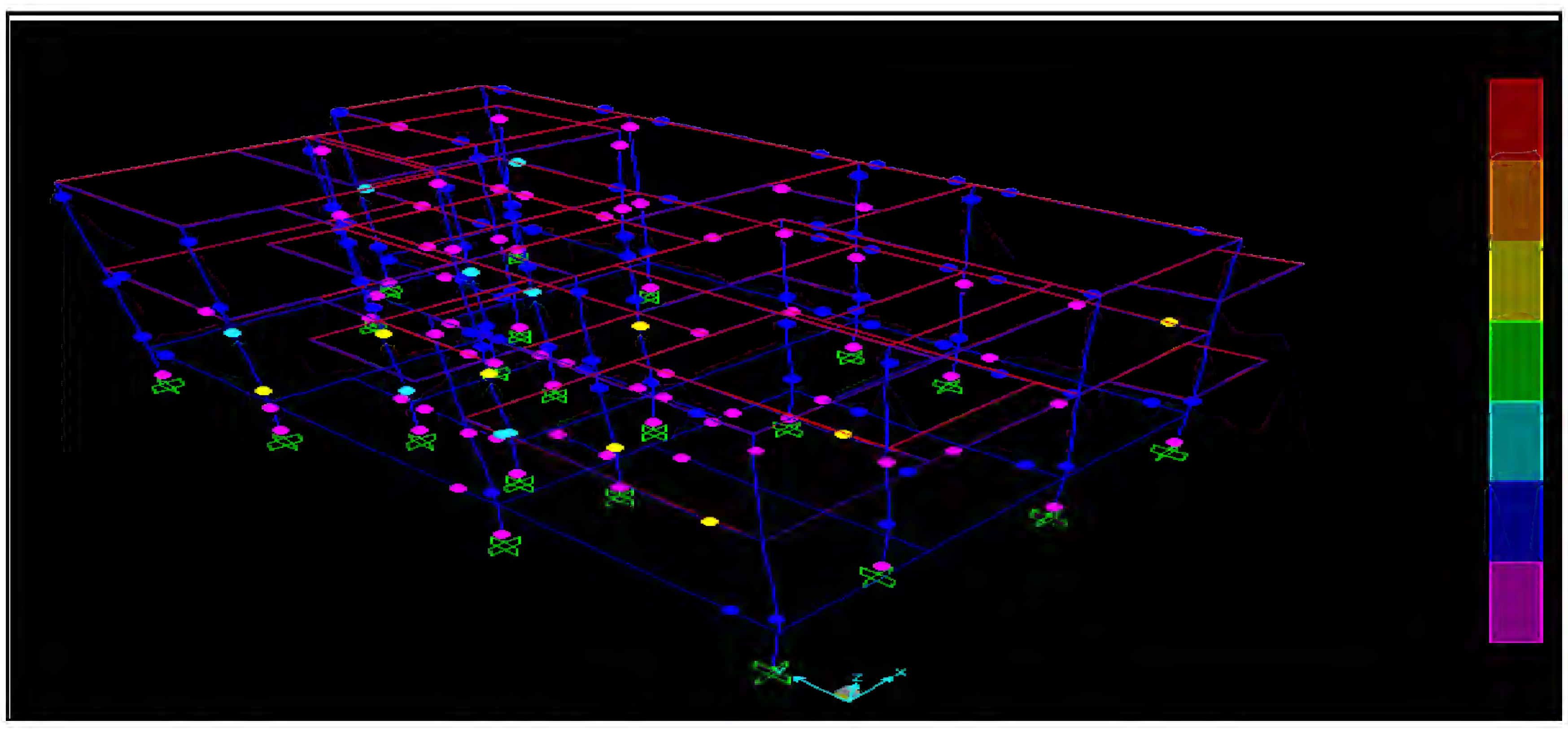

Figure 10: Hinging Pattern Due to PUSHY Case

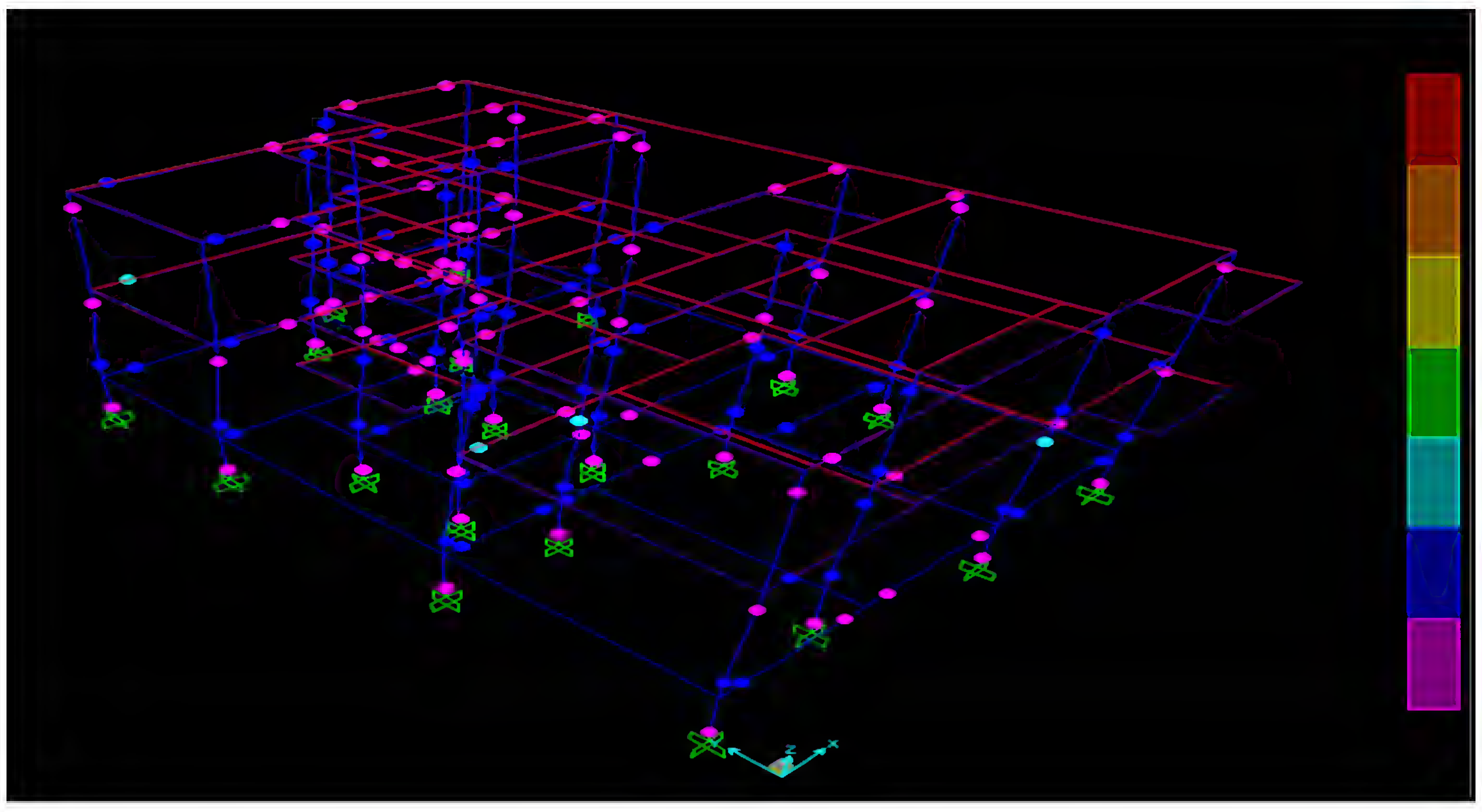

Figure 11: Hinging Pattern Due to PUSHX Case

CONCLUSIONS

In the country with 1,040 active faults covering 57% of land mass making it more prone to earthquakes, there is always a possibility that a severe earthquake in highly seismic zones might affect the performance of any structure. Therefore seismic evaluation of structures especially in severe most zones is necessary. This paper gives a rational procedure for seismic evaluation of a typical two storey unsymmetrical residential RC building is presented with a detailed pushover analysis. The purpose of this paper is to see the behavior of buildings designed and detailed by the provision of IS 1893:2002 & IS 13920: 1993 through the pushover analysis. Although the building was designed according to seismic provision laid down in present code but pushover analysis shows that still building is fails to satisfy the life safety criteria which is given according to ATC-40. In this paper the inadequacies in detailing are incorporated in the model in the form of moment rotation properties for the structural elements. This procedure gives a quick estimate of the base shear and the desirable performance of the building in its existing condition. Also this methodology is efficient in determining the deficient members and the performance of the building as a whole. The performance of the building is finally checked for code compliance and for the probable failure mechanisms. This evaluation is a prerequisite for the retrofit of the existing RC buildings in India.

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